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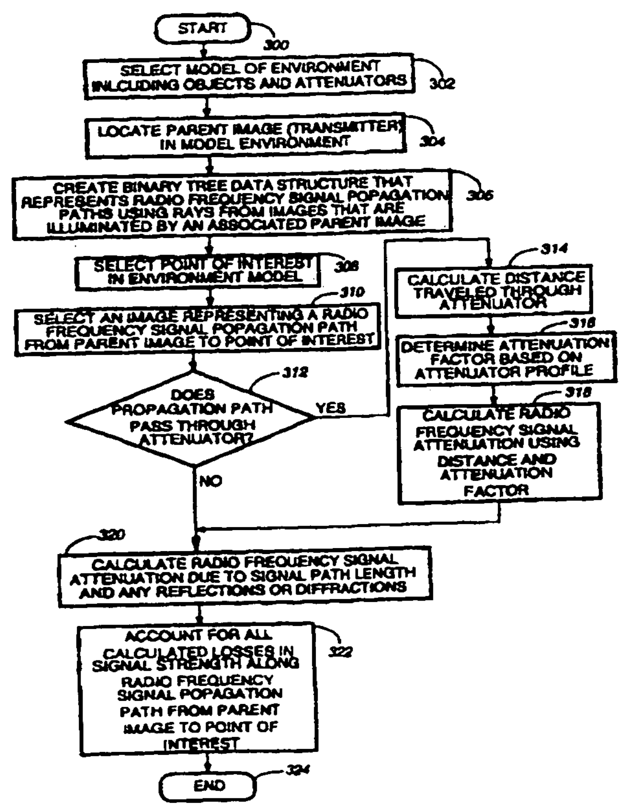
(54) Title: METHOD AND SYSTEM FOR CALCULATING A TRANSMITTED SIGNAL CHARACTERISTIC IN AN ENVIRONMENTAL MODEL HAVING ATTENUATOR FIGURES

(57) Abstract

An environmental model that locates at least one object (206) and at least one attenuator (218) in relation to a transmitter (200) is selected. A data structure (100) that represents radio frequency signal propagation paths (234) using rays (244) from images in said environmental model is created, wherein the images (240) are illuminated by radio frequency signals from parent images (200). A point of interest (228) is selected in the environmental model. Using the data structure (100), an image (240) representing a radio frequency signal propagation path (234) to the point of interest (228) is selected. A change in said transmitted signal characteristic is calculated by determining if the radio frequency signal propagation path passes through the attenuator (218) and calculating a change in the signal characteristic as a result of propagating throuth the attenuator (218). Finally, the transmitted signal characteristic at said selected point of interest (228) is calculated in response to the calculated change in the signal characteristic.



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METHOD AND SYSTEM FOR CALCULATING A TRANSMITTED SIGNAL CHARACTERISTIC IN AN ENVIRONMENTAL MODEL HAVING ATTENUATOR FIGURES

Field of the Invention

The present invention is related in general to calculating radio signal propagation, and more particularly to an improved method and system for calculating a transmitted signal characteristic in an environmental model using raytracing techniques.

Background of the Invention

In a wireless communication system, such as a cellular telephone system or personal communications services (PCS) system, base station antennas should be located so that suitable radio signals are available everywhere in the service area.

One way to ensure adequate signal coverage in the service area is to copiously locate base stations and their antennas in the service area. This solution is not practical because purchasing base station equipment and leasing property for base station equipment and antennas is expensive. Therefore, communication systems providers attempt to lower the cost of the communications system by using a minimum number of base stations, each located so that its coverage area does not excessively overlap the coverage of another.

Another problem in locating base station antennas is obtaining adequate signal coverage in areas having various objects that impede radio frequency signal propagation. For example, in a business district or a downtown area of a higher-population city, such objects may include buildings, parking garages, and trees. The presence of these objects may require strategically placed base station antennas to provide adequate signal coverage in areas that might otherwise be in a blind spot.

To correctly locate base station antennas in a radio communications system, it is important to be able to accurately predict signal strength, or another signal characteristic, in the service area when a base station antenna is placed in a particular location. Such a prediction is the goal of many so-called raytracing programs. One problem with raytracing programs is that they don't accurately predict actual measured signal characteristics in the signal area. If a signal characteristic such as signal strength is over estimated, radio communications providers may spend more money than needed to provide communications services. On the other hand, if signal characteristics are under estimated, customers may be disappointed with the quality of services.

One reason raytracing programs are not more accurate in producing a signal strength picture is because the model used to predict signal propagation does not take into account some characteristic of the environment that affects the signal. Among other things, current raytracing programs analyze propagating signals which are reflected by walls of buildings and diffracted by corners of buildings. In modeling the coverage area, raytracing programs represent building walls as objects or panels. Each panel has properties that describe the affects of a wall on a propagating signal. Such properties include reflection coefficients and mathematical expressions that describe radio wave diffraction at the corner of the panel.

For further illustration, **FIG. 1** depicts a transmitted signal reflecting off of an object or panel, and an associated reflected image. As shown, transmitter **20** is located relative to panel **22** in environment model **24**. Environment model **24** represents, for example, a portion of the coverage area having buildings that redirect propagating signals radiating from a transmitter antenna. In this example, transmitter **20** is selected to radiate transmitted signals in a radiation pattern or arc **26** defined by rays **28** and **30**.

After leaving transmitter **20**, transmitted signals propagate toward panel **22** and reflect off of panel **22** with a signal strength determined by

the material of panel **22** and the incident angle between the ray and panel **22**. Thus, in **FIG. 1**, ray **28** reflects off of panel **22** to produce ray **32**, and ray **30** reflects to produce ray **34**. The signal strength of ray **32** depends upon the distance traveled by ray **28**, incident angle **36**, and the reflection coefficient of panel **22**.

Note that the signals reflected off of panel **22**, such as ray **32** and **34**, can be represented as conceptual or virtual rays coming from another point source, represented here by child image **38**, which can be thought of as the origin of rays **32** and **34**. Representing reflected signals as signals transmitted from a child image is a means for simplifying the raytracing problem.

When propagating signals strike a corner, such as the corner of building **46** in **FIG. 2**, the transmitted signal is diffracted, as indicated by rays **48** and **50**. Such a corner, which is called a diffraction corner, may occur at the end of a panel, such as the panels that make up building **46**.

Because diffracted rays **48** and **50** behave as though they emanated from diffraction corner **52**, diffraction corner **52** may be represented by a child image at the same location, which, again, simplifies the raytracing problem.

With reference now to **FIG. 3**, there is depicted a more complex environmental model of a communications system service area. If a system designer wants to know the total signal strength of a signal transmitted from transmitter **60** arriving at point of interest **62**, the designer must consider signal power propagating directly from transmitter **60** to point of interest **62**, as well as reflected and diffracted signal power arriving at point of interest **62**. Thus, diffracted signals and signals reflecting off of buildings **64** and **66** may be modeled as rays coming from child images, and grandchild images. To make the problem tractable, the number of decendent images may be limited as specified by the user, or by an algorithm which considers the power contributed by each decendent image.

After locating images in the environment model, total signal strength at point of interest **62** may be calculated by accounting for contributions from transmitter **60** through ray **68**, from child image **70** through ray **72**, from child image **74** through ray **76**, and from grandchild image **78** through ray **80**. Image **78** is referred to as a grandchild image because that image is a child of a child image. That is, grandchild image **78** is energized, or receives energy from, child image **70**. Note that grandchild image **78** is not energized by transmitter **60** (the parent image) because the path between transmitter **60** and grandchild image **78** is obstructed by panel **82**.

As may be seen, it doesn't take a very complicated environmental model to produce a tedious calculation for determining the signal strength, or other signal characteristic, of a transmit signal at a point of interest. Furthermore, to be most useful, thousands of points of interest at specified intervals must be considered to produce a useful map of signal coverage in a service area.

With reference now to **FIG. 4**, there is depicted a tree **100**, which is a data structure that may be used in raytracing programs to represent or aid in the calculation of signal propagation paths. In tree **100**, each node, such as parent node **102**, may point to, or be associated with, a child node, such as child nodes **104** and **106**. Similarly, child nodes may point to a grandchild node, and a grandchild node may point to a great grandchild node, such as grandchild node **108** and great grandchild node **110**. The same node, say node **108**, may be a child node with respect to node **104** one level up, and a grandchild node with respect to node **102** two levels up. Thus, these child-node expressions are relative expressions.

The environment model in **FIG. 3** may be represented as a tree. For example, transmitter **60** may be represented in tree **100** as parent node **102**. Child image **70** in **FIG. 3** may be represented as child node **104** in **FIG. 4**. Child node **104** is associated with parent node **102** because child image **70** derives its energy from transmitter **60**. It may be said that child image **70** energized or illuminated by transmitter **60**. Similarly, child image **74**

may be represented in tree **100** by child node **106**. Child nodes **104** and **106** have direct links to parent node **102** because child images **70** and **74** are directly energized by rays from transmitter **60** in **FIG. 3**. Child image **78**, however, is energized by a reflection off of building **64**. Therefore, child image **78** is represented in tree **100** as grandchild node **108**. Any rays emanating from child node **78** that strike additional panels to create child images will be represented as a great grandchild node, such as great grandchild node **110**. In this manner, the parent image, or transmitter **60**, and derivative child images in **FIG. 3** may be represented by a tree, such as tree **100** in **FIG. 4**.

To aid in calculating signal characteristics at a point of interest in the environment model, each node in tree **100** may be associated or linked with various types of data, including location of the node, type of node (reflection or diffraction), scope of the node (angles at which rays depart from the node). This technique for organizing data allows the raytracing program to calculate the effects of each bounce or diffraction along the path between the transmitter and the point of interest.

Even though raytracing programs tediously predict multiple signal paths and account for transmitted signal characteristics contributed by each of theses paths, there are still differences between predicted signal characteristics and measured signal characteristics. To save money and insure quality service, it is important to eliminate or reduce the difference between predicted and measured values. Therefore, a need exists for an improved method and system for calculating transmitted signal characteristics in an environmental model that more accurately models a service area and predicts signal characteristics close to those that are actually measured in the modeled service area.

Brief Description of the Drawings

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objects, and advantages thereof, will best be

understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

FIG. 1 depicts a transmitted signal reflecting off of a panel;

FIG. 2 depicts diffraction of a transmitted signal;

FIG. 3 illustrates an environment model of a wireless system service area;

FIG. 4 depicts a data structure for representing the propagation of radio frequency signals in a raytracing program;

FIG. 5 illustrates a data processing system that may be used to implement the method and system of the present invention;

FIG. 6 depicts an environment model of a wireless communications system that locates objects and attenuators in relation to a transmitter antenna in accordance with an embodiment of the method and system of the present invention; and

FIG. 7 is a high-level logical flowchart that illustrates the operation of an embodiment of the method and system of the present invention.

Detailed Description of the Invention

With reference now to **FIG. 5**, there is depicted a data processing system **140**, which may be used to implement an embodiment of the method and system of the present invention. Data processing system **140** may include processor **142**, keyboard **144**, display **146**, and pointing device **148**. Keyboard **144** provides means for entering data and commands into processor **142**. Display **146** may be implemented utilizing any known means for displaying textual, graphical, or video images, such as a cathode ray tube (CRT), a liquid crystal display (LCD), an electroluminescent panel, or the like. Pointing device **148** may be implemented utilizing any known pointing device, such as a trackball, joystick, touch sensitive tablet or screen, track pad, or as illustrated in **FIG. 5**, a mouse. Pointing device **148** may be utilized to move a pointer or a cursor on display **146**.

Processor **142** may be coupled to one or more peripheral devices, such as CD-ROM **150**.

Data processing system **140** includes means for reading data from a storage device. Such means for reading data may include: a hard disk drive internal or external to processor **142** (not shown); a tape drive (not shown); floppy disk drive **152**, which reads and writes floppy disks **154**; or CD-ROM **150**, which reads and/or writes compact disk **156**. Such storage means may be referred to as a computer usable medium for storing computer readable program code in the form of data and software.

Data processing system **140** may also be coupled to a network which permits the transfer of data and software between data processing systems. Using such a network, programs can be loaded into data processing system **140**.

The components of data processing system **140** discussed above may each be implemented utilizing any one of several known off-the-shelf components. For example, data processing system **140** may be implemented utilizing any general purpose computer or so-called workstation, such as the workstation sold under the name "Model 712/60" by Hewlett-Packard Company of Palo Alto, CA.

When performing a ray tracing simulation, it is important to model all objects in the service area that can affect the propagation of radio frequency signals between the base antenna location and the location of a subscriber unit. For example, trees and other foliage may be modeled to attenuate radio frequency signal power at rates that depend upon the type of foliage and the frequency of interest. In addition to an attenuation per linear distance travel through the tree or attenuator, attenuator models may also be non-linear. This means that an attenuation factor per unit distance through the attenuator may depend upon where on the attenuator figure the radio frequency signal enters the attenuator, and the angle of incidence between the ray entering the attenuator and the surface of the attenuator. Thus, a model of a tree may have a complex shape and a non-linear attenuation profile that depends

upon the point of entry into the attenuator, the angle of entry, and the path through the attenuator.

With reference now to **FIG. 6**, there is a depicted an environmental model of a wireless communications system that locates objects and attenuators in relation to a base station transmitter antenna in accordance with the method and system of the present invention. As illustrated, transmitter antenna **200** is located near building **202**. In this environmental model, buildings are formed by a plurality of panels. For example, building **204** includes panels **206** and **208** and additional panels (not shown) that form the other walls of building **204**. Building **210** includes panel **212**.

Also included in the environment model shown in **FIG. 6** are attenuators, which in this example are trees **214** through **224**. Although the attenuators in this example are trees, attenuators may be any object that changes a characteristic, such as signal strength, of a radio frequency signal without changing the direction of propagation for at least a portion of the signal. Other examples of attenuators include shrubs, billboards or signs, newsstands or other small structures, or other buildings that allow radio waves to propagate through, over, or around them.

In order to more accurately model trees **214** through **224**, such trees may be represented by a compound three dimensional model that includes trunk **226** and foliage **218**. Trunk **226** extends upward from the ground to a pre-selected height where the trunk ends and foliage **218** begins. In one embodiment, trunk **226** and foliage **218** are modeled with cylindrical shapes stacked one upon the other. Other attenuating objects may be modeled with appropriate three dimensional figures.

In the example of **FIG. 6**, the selected point of interest **228** is located in street **230**. Point of interest **228** is the point in the environment model that is used for calculating the transmitted signal characteristic, which in one embodiment of the present invention is signal strength. To calculate signal strength at point of interest **228**, several radio frequency signal propagation paths from transmitter antenna **200** to point of interest **228**

may be considered. The paths shown in this example are only a small subset of the several radio frequency signal propagation paths that are possible. This subset was selected to illustrate the operating principles of the present invention.

The three radio frequency signal propagation paths shown in **FIG. 6** are labeled with reference numbers **232** through **236**. Notice that each signal path includes a change of direction as a result of either a reflection or a diffraction. Signal path **232** is reflected by panel **206**. Signal path **234** is diffracted by diffraction corner **238**. And signal path **236** is reflected by panel **212**.

Signal paths **232** and **236** are represented in a computer data structure with the aid of images **240** and **242**, respectively. The modeling technique used in the present invention uses rays from images in the environment model to illuminate the point of interest. For example, image **240**, which is located opposite transmitter antenna **200** along a perpendicular line that intersects panel **206**, emits ray **244**, a conceptual or virtual ray that can illuminate or radiate radio frequency signal power on an object located at point of interest **228**. Notice that a portion of ray **244** represents the portion of radio frequency signal propagation path **232** after it has been reflected off of panel **206**.

Images **240** and **242** are represented in a data structure as locations in the environmental model from which radio frequency signals propagate. In a similar manner, diffraction corner **238** is also represented in the data structure as a source of radio frequency signals.

Of the signal propagation paths shown in **FIG. 6**, both radio frequency signal propagation paths **232** and **234** pass through an attenuator. Propagation path **232** passes through trees **216** and **218**, and path **234** passes through tree **218**. In more precise models according to the method and system of the present invention, the attenuation of signal strength, or other variation in signal characteristic, is dependent upon the distance traveled through the attenuator and the location of the propagation path in the attenuator. For example, propagation path **232**

passes through an off-center portion of tree **216**. Additionally, propagation path **232** does not pass through the trunk portion of tree **216**. In contrast, propagation path **234** passes through the center of tree **218**, and may also pass through trunk **226**, depending upon the elevation of propagation path **234**.

In an attenuation profile that describes the attenuation properties of particular attenuators, a signal that passes through the center of an attenuator may be attenuated at a different rate than a signal that passes through another portion of attenuator. In the case of a tree, this is because a radio frequency signal that passes through the center of a tree is more likely to hit larger branches or portions of the trunk, which would appear as a different loss per meter than the loss per meter at the outer fringes of the tree's foliage which has fewer branches.

With reference now to **FIG. 7**, there is depicted a high-level logical flow chart that illustrates the operation of an embodiment of the method and system of the present invention. As illustrated, the process begins at block **300** and thereafter passes to block **302** wherein an environmental model of at least a portion of the wireless communications system is selected. In this selected model, objects and attenuators are located relative to one another. Objects include buildings and structures (which may be modeled with panels) that can redirect a propagating signal transmitted from a transmitter antenna. Such redirection of a signal occurs through reflection or diffraction. Objects are used to model structures that are made of various materials. These materials are modeled with coefficients that are used to calculate the characteristics of reflected or diffracted signals. Thus, depending upon the material, reflected or diffracted signal characteristics are affected in different ways.

Attenuators include structures that modify a signal characteristic, such as signal strength, without substantially changing the direction of the propagating signal. An example of an attenuator is a tree. Attenuators may be modeled as three dimensional figures, or as compound figures, as in the trees having a foliage part and a trunk part

discussed above. These attenuators may also have an attenuation profile that describes how an attenuation factor varies depending upon the location of the signal path in the attenuator. This means that propagating signals passing through the center of a tree may be attenuated at a different rate than a signal propagating through the outer edge of a tree.

Next, the parent image or transmitter image is located in the model, as depicted at block **304**. Selection of the parent image is allowed so that proposed transmitter locations may be evaluated for signal coverage in the environment model.

Once the transmitter has been located, the process creates a data structure, such as a binary tree data structure, that represents radio frequency signal propagation paths using rays from images that are illuminated by an associated parent image, as illustrated at block **306**. When an image is illuminated by a parent, that image receives its signal power from an associated parent image. For example, image **240** is illuminated by its parent image, transmitter antenna **200**. The association between image **240** and its parent, transmitter antenna **200**, may be illustrated by the fact that image **240** would not exist if transmitter antenna **200** was not there.

Next, a point of interest is selected in the environment model, as depicted at block **308**. Points of interest are typically selected at locations where a subscriber unit is likely to be found. In the example shown in **FIG. 6**, point of interest **228** is selected in street **230**. In order to develop a map that represents a selected signal characteristic over an entire coverage area, such a point of interest is iteratively selected at different locations in the environment model.

After selecting a point of interest, an image that represents at least a portion of a radio frequency signal path from an associated parent image to the point of interest is selected, as illustrated at block **310**. One way to select such an image is to look for an image, from the point of view of the point of interest, that is not blocked by another panel (not counting the panel responsible for generating the reflected image). For example, in

FIG. 6, three images are visible from point of interest 228—images 240 and 242, and diffraction corner 238.

After selecting an image, the process determines whether or not the radio frequency signal propagation path associated with the selected image passes through an attenuator, as depicted at block 312. Thus, if image 240 is the selected image, the process determines whether or not the signal propagation path associated with image 240—signal path 232—intersects or passes through an attenuator. In the case of signal path 232, the signal passes through two attenuators—tree 216 along a leg of signal path 232 that is before the reflection, and tree 218 along the leg of signal path 232 after the reflection.

In some embodiments of the present invention, signal path 232 may be analyzed in three dimensions. Thus, in a three dimensional model, the process may determine whether or not signal path 232 passes above or below the foliage of tree 216. In the case where a compound figure is used, the process may determine whether or not the signal path passes through the foliage portion of a tree or the trunk portion of a tree.

If the signal propagation path passes through an attenuator, the process calculates the distance that the propagating signal traveled through such an attenuator, as illustrated at block 314. In the case where the attenuator is modeled as a cylinder, this involves calculating the length of a chord formed by the intersection of the cylinder and a line representing the signal path. That is, calculating the length of the line between the entry point and the exit point of the attenuator.

Thereafter, the process determines the attenuation factor based upon the attenuator profile, as depicted at block 316. Such an attenuator profile describes how the attenuator attenuates a propagating signal depending upon the location of the signal path in the attenuator. Such an attenuator profile may specify, for example, that a signal passing through the center of a tree is attenuated more per unit distance than a signal entering the fringes or outer edges of the tree. Such an attenuator profile may also include information about signal attenuation based upon

an incident angle between the signal path and the surface of the attenuator. Such an incident angle may require more analysis when the angle is not so predictable, as when the shape of the attenuator is a polygon rather than a circle

After the attenuation factor and the distance traveled through the attenuator are known, the process calculates the radio frequency signal attenuation that results from passing through the attenuator, as illustrated at block **318**. Although the embodiment described in the flow chart of **FIG. 7** calculates radio frequency signal attenuation, other signal characteristics may be calculated as a result of more complex models which combine signal scattering from leaves, diffraction, reflection, transmission, and attenuation, in combination for the estimated sizes, density and distribution of the leaves. Statistical averages relating the radio frequency properties may also be used on tree parameters, including foliage density, moisture content, size, shape, and type of tree. These more complex models can be used to obtain an attenuation for a path, modeled as a ray, that passes through the foliage.

With reference again to block **312**, if the propagation path does not pass through an attenuator, the process calculates the radio frequency signal attenuation due to signal path length, including signal paths before and after any reflections or diffractions, and attenuation due to any reflections or diffractions, as depicted at block 320. Thus, the radio frequency signal attenuation due to free air propagation between transmitter antenna **200** and panel **206**, and between panel **206** and point of interest **228** are calculated. In addition to free air attenuation over the length of the path, any attenuation that occurs during the reflection off of panel **206** is also calculated.

And finally, the process accounts for all calculated losses in signal strength along the radio frequency signal propagation path from the parent image to the point of interest, as illustrated at block **322**. This accounting includes losses calculated in block **320** and in block **318** if the propagation path passes through an attenuator.

Before ending at block **324**, the process may loop from block **322** back to block **310** to select additional images that are capable of illuminating the selected point of interest. This allows signal strength calculations at a point of interest to consider signal power received from multiple signal propagation paths. Examples of other images that can illuminate point of interest **228** include image **242**, which is associated with a path that does not pass through an attenuator, and image **238**, which is a diffraction corner associated with a signal path that passes through tree **218**, and maybe through trunk **226**.

Additionally, the process may also iteratively loop back from block **322** to block **308** to select a new point of interest in a process that constructs a map showing signal characteristics at all points in the environment model.

As indicated above, aspects of this invention pertain to specific method functions implementable on computer systems. In an alternate embodiment, the invention may be implemented as a computer program product for use with a computer or data processing system. Those skilled in the art should readily appreciate that programs defining the functions of the present invention can be delivered to a computer in many forms, which include, but are not limited to: (1) information permanently stored in non-writable storage media (e.g. read-only memory devices such as ROM chips, or CD-ROM disks **156**—readable by a computer I/O attachment such as CD-ROM reader **150**); (2) information alterably stored on writable storage media (e.g. hard disk drives and floppy disks **154**); or (3) information conveyed to a computer through communication media, such as a network, the public switched telephone network, a fiber optic cable, and transmitted radio frequency signals. It should be understood, therefore, that such media, when carrying computer readable instructions that direct the method functions of the present invention, represent alternate embodiments of the present invention.

Although the method and system of the present invention has been described with an example that calculates signal strength in a service

area, those persons skilled in the art should recognize that other signal characteristics, such as a bit error rate, or a signal delay spread, may be calculated.

As described above, the method and system of the present invention more accurately predicts transmitted signal characteristics, such as signal strength, in a model of a communications system service area. More accurate predictions enable system designers to provide quality communications services without the cost of over designing the system with overlapping signal coverage between cell sites. More accurate predictions also expose signal coverage problems, which may then be fixed before customers are annoyed by poor service.

The foregoing description of a preferred embodiment of the invention has been presented for the purpose of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The embodiment was chosen and described to provide the best illustration of the principles of the invention and its practical application, and to enable one of ordinary skill in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

Claims

What is claimed is:

1. A method for calculating a transmitted signal characteristic in an environmental model, said method comprising the steps of:

selecting an environment model that locates at least one object (206) and at least one attenuator (216) in relation to a transmitter (200);

creating a data structure (100) that represents radio frequency signal propagation paths (232) using rays (244) from images (240) in said environmental model, wherein said images (240) are illuminated by radio frequency signals from parent images (200);

selecting a point of interest (228) in said environment model;

using said data structure (100), selecting one of said images (240) representing a radio frequency signal propagation path (244) from said parent image to said point of interest (228);

calculating a change in said transmitted signal characteristic resulting from signal propagation over said radio frequency signal propagation path (232) from said parent image (200) to said point of interest (228) by:

determining (312) if said radio frequency signal propagation path passes through said attenuator (216);

calculating a change (318) in said signal characteristic as a result of propagating through said attenuator; and

calculating (320, 322) said transmitted signal characteristic at said selected point of interest in response to said calculated change in said signal characteristic.

2. The method for calculating a transmitted signal characteristic according to claim 1 wherein said at least one attenuator is a tree, and wherein said step of selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter includes selecting an environment model that locates at least one object and at least one tree in relation to a transmitter.

3. The method for calculating a transmitted signal characteristic according to claim 1 wherein said at least one object is a reflection panel, and wherein said step of selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter includes selecting an environment model that locates at least one reflection panel and at least one attenuator in relation to a transmitter.

4. The method for calculating a transmitted signal characteristic according to claim 1 wherein said at least one object is a diffraction corner, and wherein said step of selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter includes selecting an environment model that locates at least one diffraction corner and at least one attenuator in relation to a transmitter.

5. The method for calculating a transmitted signal characteristic according to claim 1 wherein said transmitted signal characteristic is signal power.

6. The method for calculating a transmitted signal characteristic according to claim 1 wherein said attenuator is a cylindrical representation of a tree, and wherein said step of determining if said radio frequency signal propagation path passes through said attenuator further includes determining if said radio frequency signal propagation path passes through said cylindrical representation of a tree.

7. The method for calculating a transmitted signal characteristic according to claim 1 wherein said change said attenuator has upon said transmitted signal characteristic is a function of the path through said attenuator, and wherein said step of calculating a change in said signal characteristic as a result of propagating through said attenuator further includes calculating a change in said signal characteristic as a result of propagating along a particular path through said attenuator.

8. A system for calculating a transmitted signal characteristic in an environmental model comprising:

means for selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter;

means for creating a data structure that represents radio frequency signal propagation paths using rays from images in said environmental model, wherein said images are illuminated by radio frequency signals from parent images;

means for selecting a point of interest in said environment model;

means for using said data structure, selecting one of said images representing a radio frequency signal propagation path from said parent image to said point of interest;

means for calculating a change in said transmitted signal characteristic resulting from signal propagation over said radio frequency signal propagation path from said parent image to said point of interest by:

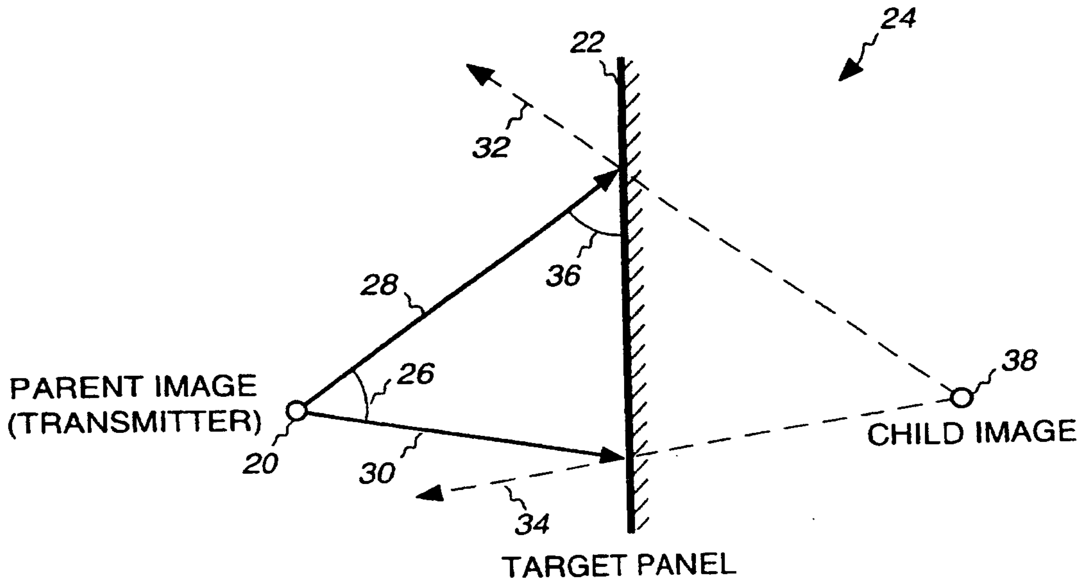
means for determining if said radio frequency signal propagation path passes through said attenuator;

means for calculating a change in said signal characteristic as a result of propagating through said attenuator; and

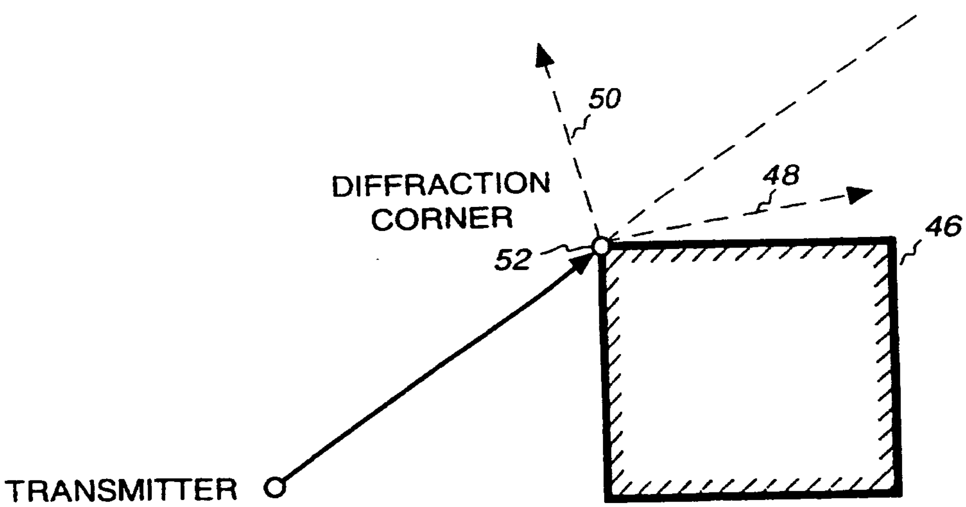
means for calculating said transmitted signal characteristic at said selected point of interest in response to said calculated change in said signal characteristic.

9. The system for calculating a transmitted signal characteristic according to claim 8 wherein said at least one attenuator is a tree, and wherein said means for selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter includes means for selecting an environment model that locates at least one object and at least one tree in relation to a transmitter.

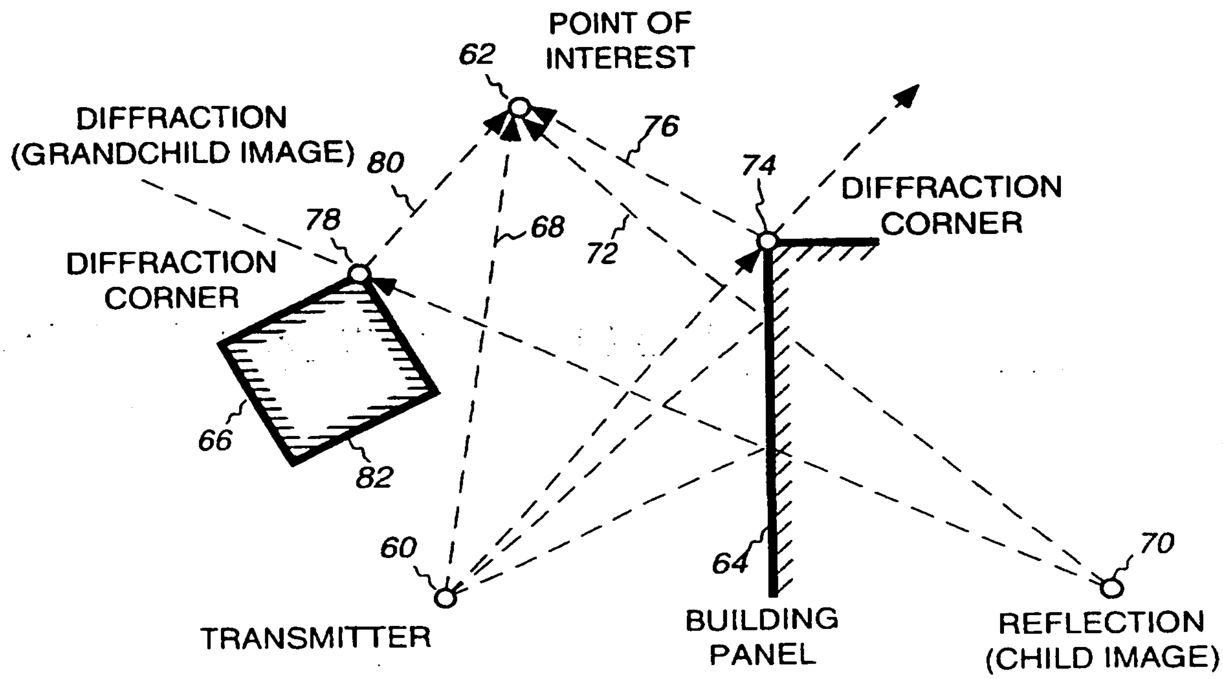
10. The system for calculating a transmitted signal characteristic according to claim 8 wherein said attenuator is a representation of a tree including a cylinder shaped trunk portion and a cylinder shaped foliage portion, and wherein said means for determining if said radio frequency signal propagation path passes through said attenuator further includes means for determining if said radio frequency signal propagation path passes through said representation of a tree including a cylinder shaped trunk portion and a cylinder shaped foliage portion.



Prior Art
FIG. 1



Prior Art
FIG. 2



POINT OF INTEREST
62
DIFFRACTION (GRANDCHILD IMAGE)
80
76
74
DIFFRACTION CORNER
78
68
72
DIFFRACTION CORNER
66
82
60
64
70
TRANSMITTER
BUILDING PANEL
REFLECTION (CHILD IMAGE)

FIG. 3

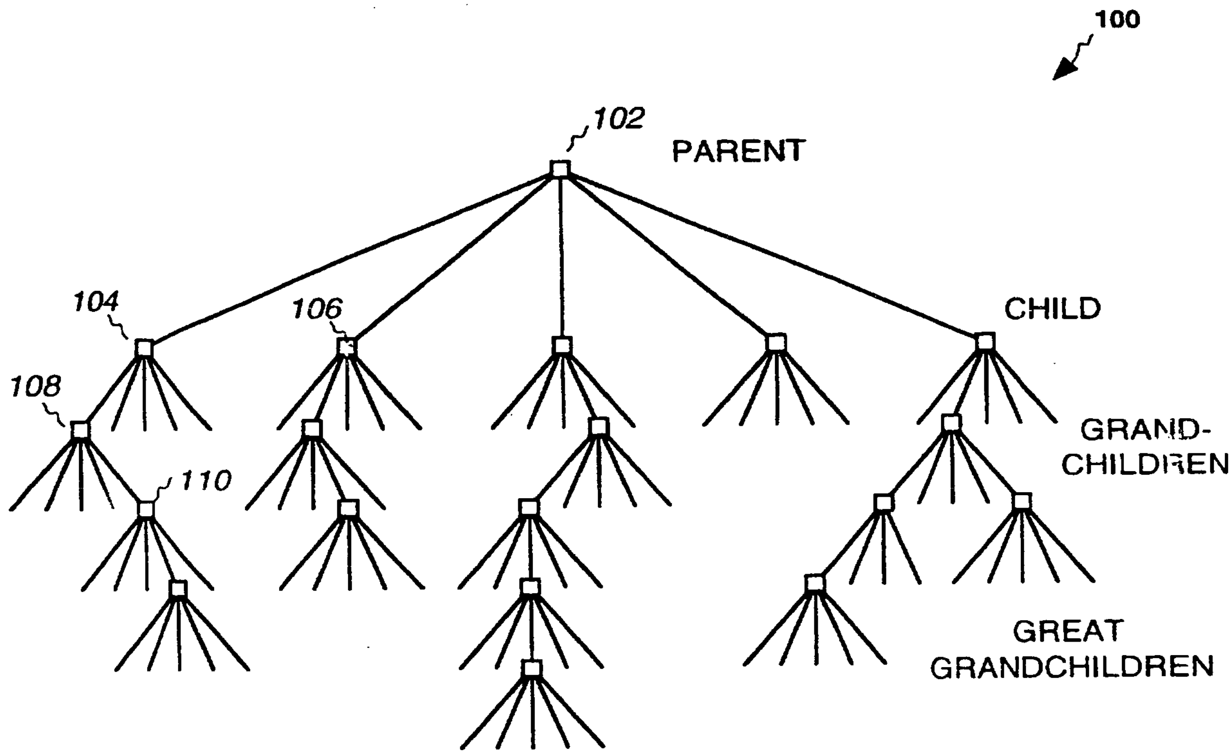

100
102
PARENT
104
106
108
110
CHILD
GRAND-
CHILDREN
GREAT
GRANDCHILDREN

FIG. 4

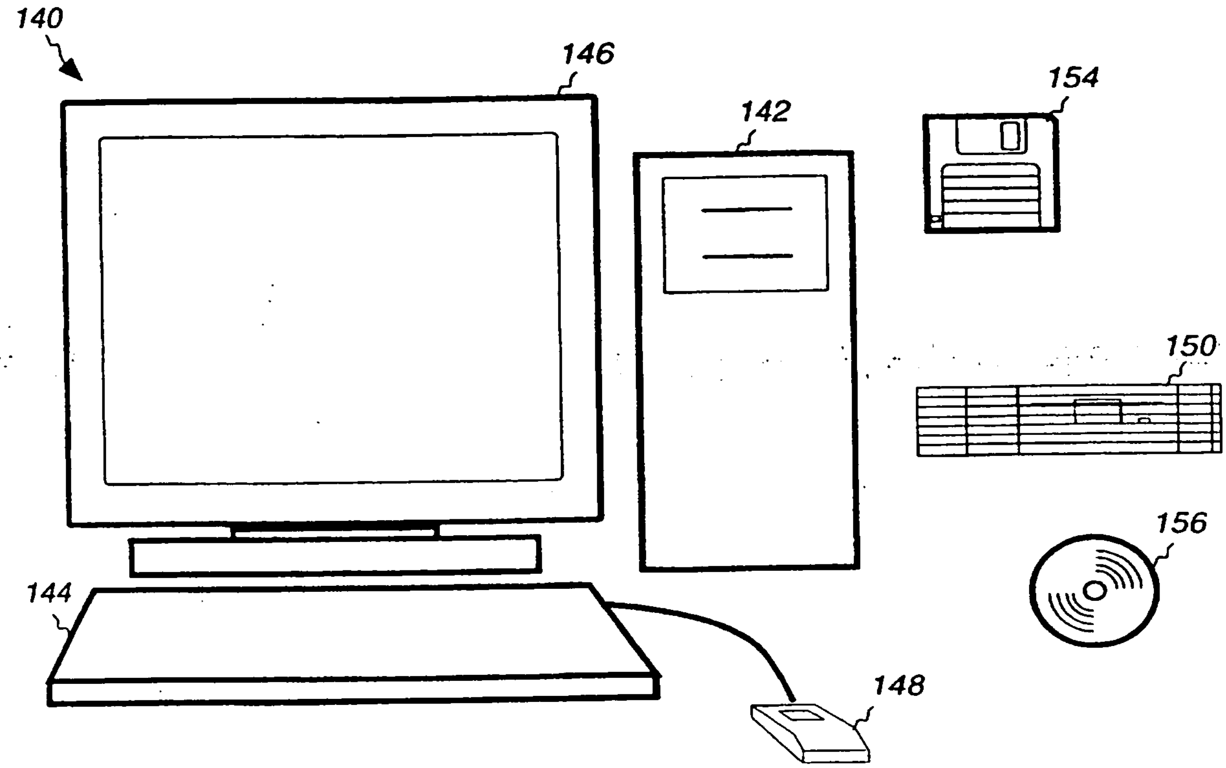
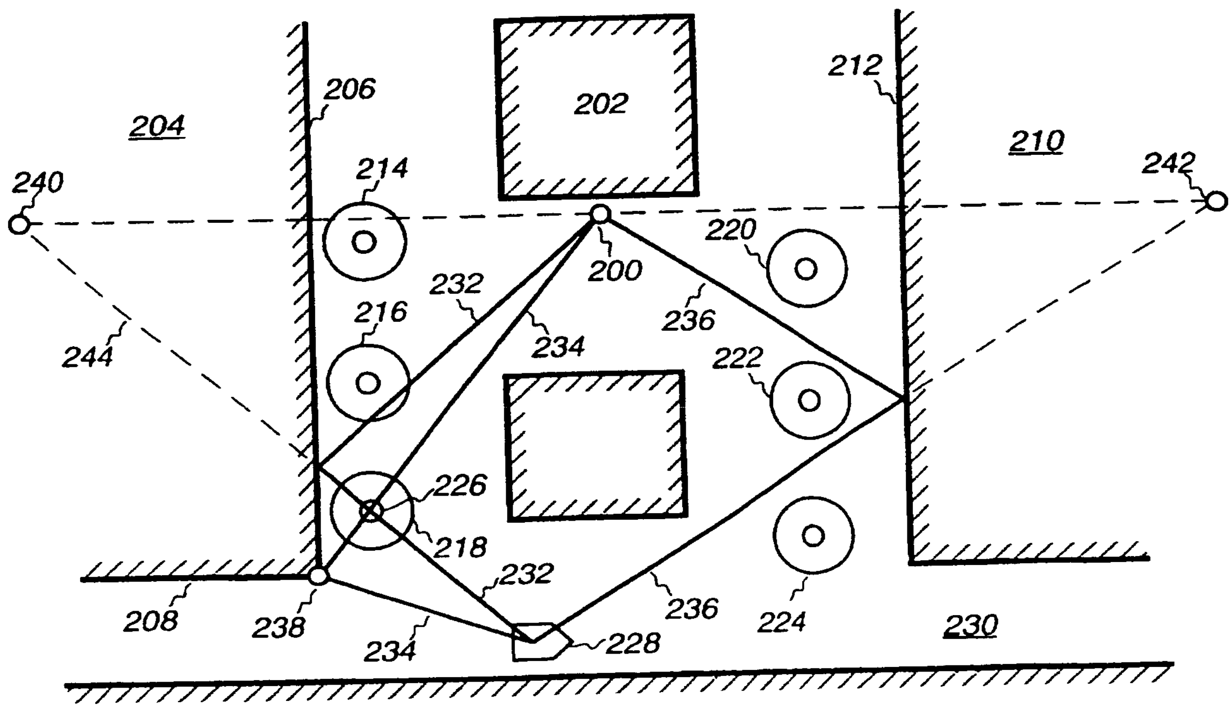


FIG. 5


204
206
202
212
210
240
214
242
220
200
232
236
216
234
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238
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228

FIG. 6

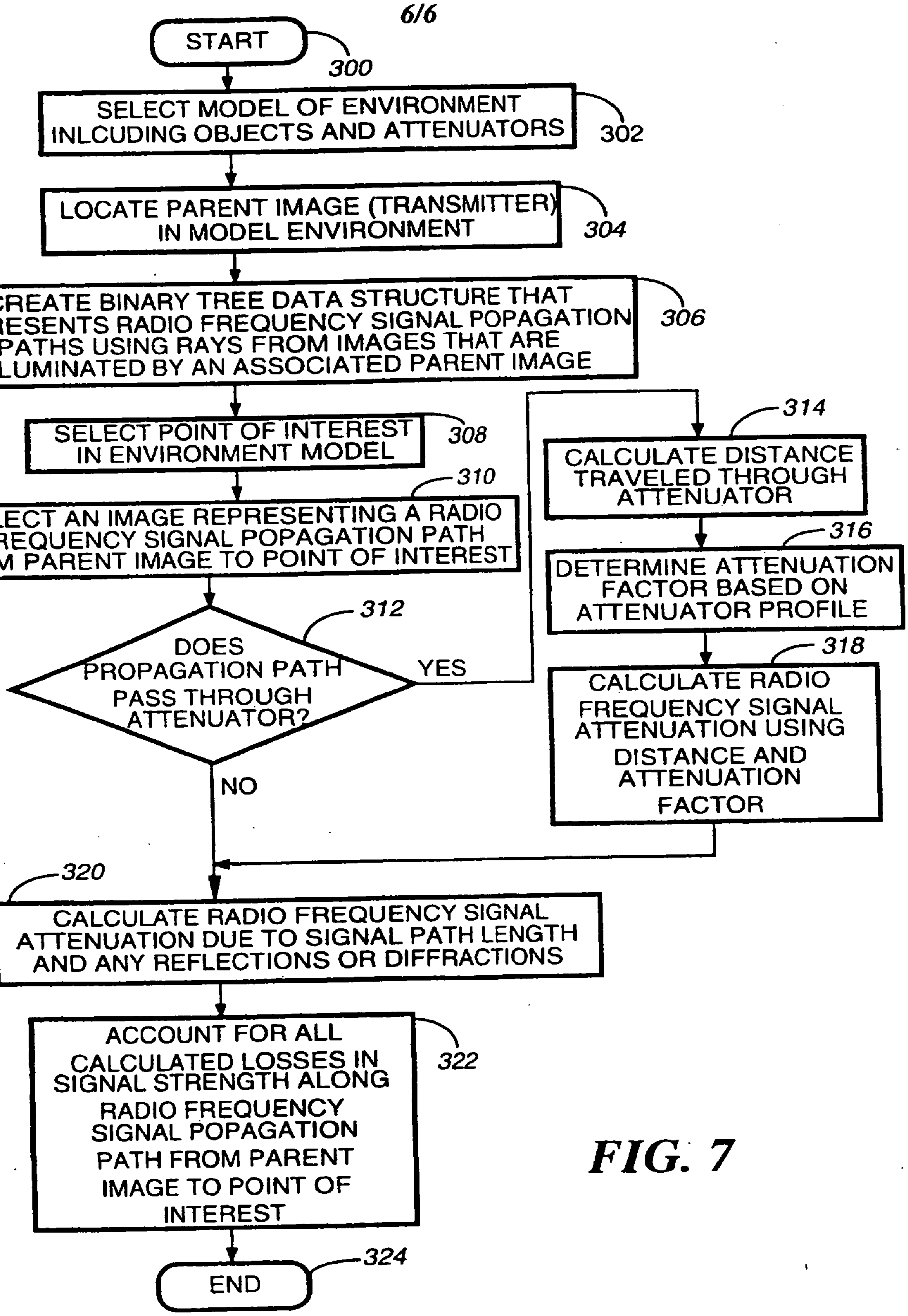
START
300
SELECT MODEL OF ENVIRONMENT INLCUDING OBJECTS AND ATTENUATORS
302
LOCATE PARENT IMAGE (TRANSMITTER) IN MODEL ENVIRONMENT
304
CREATE BINARY TREE DATA STRUCTURE THAT REPRESENTS RADIO FREQUENCY SIGNAL POPAGATION PATHS USING RAYS FROM IMAGES THAT ARE ILLUMINATED BY AN ASSOCIATED PARENT IMAGE
306
SELECT POINT OF INTEREST IN ENVIRONMENT MODEL
308
SELECT AN IMAGE REPRESENTING A RADIO FREQUENCY SIGNAL POPAGATION PATH FROM PARENT IMAGE TO POINT OF INTEREST
310
DOES PROPAGATION PATH PASS THROUGH ATTENUATOR?
312
YES
NO
CALCULATE DISTANCE TRAVELED THROUGH ATTENUATOR
314
DETERMINE ATTENUATION FACTOR BASED ON ATTENUATOR PROFILE
316
CALCULATE RADIO FREQUENCY SIGNAL ATTENUATION USING DISTANCE AND ATTENUATION FACTOR
318
CALCULATE RADIO FREQUENCY SIGNAL ATTENUATION DUE TO SIGNAL PATH LENGTH AND ANY REFLECTIONS OR DIFFRACTIONS
320
ACCOUNT FOR ALL CALCULATED LOSSES IN SIGNAL STRENGTH ALONG RADIO FREQUENCY SIGNAL POPAGATION PATH FROM PARENT IMAGE TO POINT OF INTEREST
322
END
324

FIG. 7

INTERNATIONAL SEARCH REPORT	International application No. PCT/US97/08569

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 17/00
US CL :455/67.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/67.1, 67.3, 67.4, 67.6, 67.7, 422, 423, 424, 507, 517, 62, 63, 115

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS: RAY TRACING

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P	US 5,623,429 A (FORTUNE ET AL) 22 APRIL 1997, see figs. 3-4.	1-9, 12-21, 24-33, 36
X	US 5,450,615 A (FORTUNE ET AL) 12 SEPTEMBER 1995, see figs. 1-5.	1-9, 12-21, 24-33, 36
A, P	US 5,574,466 A (REED ET AL) 12 NOVEMBER 1996, see figs. 1-4.	1-36

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 AUGUST 1997	03 SEP 1997

Name and mailing address of the ISA/US	Authorized officer
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